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WATER TREATMENT PLANT PROCESSES AND OPERATIONS

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Environmental Protection Agency
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PLANT PROCESSES
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LEE, RAMON C

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WATER TREATMENT PLANT PROCESSES AND OPERATIONS

Course Outline

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INTRODUCTION

A. Definitions:

1. Absorption - the taking up of one substance into the body of another.
2. Adsorption - the adherence or attachment of dissolved, colloidal or finely divided solids on the surface of solid bodies with which they are brought in contact.
3. Alkalinity - a quantitative measurement of the total alkaline constituents of a water, both in the ionized and un-ionized states. Usually expressed as ppm of equivalent CaCO_3 .
4. Alkalinity, Bicarbonate - alkalinity caused by bicarbonate $(\text{HCO}_3)^-$ ions.
5. Alkalinity, Carbonate - alkalinity caused by carbonate ions. $(\text{CO}_3)^{=}$
6. Alkalinity, Hydroxide - alkalinity caused by hydroxyl ions. $(\text{OH})^-$. Caustic alkalinity.
7. Alum - the common name for aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3 \times \text{H}_2\text{O}$ often used as a coagulant in water treatment.
8. Bacterial Count - an estimate of the total number of bacteria of all kinds in a one ml sample which will grow at the stated temperature, usually 37°C .
9. Calcium Hydroxide - slaked lime. $\text{Ca}(\text{OH})_2$. Used in water treatment to remove carbonate or temporary hardness, and for pH control.
10. Calcium Hypochlorite - a compound of lime and chlorine used for disinfection purposes. $\text{Ca}(\text{OCl})_2$.
11. Caustic Soda - sodium hydroxide. NaOH .
12. Chloramine - a compound of organic amines or inorganic ammonia with chlorine. Monochloramine, NH_2Cl . Dichloramine, NHCl_2 . Also referred to as "combined available chlorine residual".
13. Chlorination, Breakpoint - the application of chlorine to water containing free ammonia to provide a free available chlorine residual.

14. Chlorine Demand - the difference between the amount of chlorine added to water and the amount of residual chlorine remaining at the end of a specified contact period.
15. Chlorine Dioxide - a heavy reddish-yellow gas with a pungent disagreeable odor and soluble in water. Has disinfecting properties but used primarily for taste and odor control, ClO_2 .
16. Colloid - a suspension of finely divided solids which will not settle readily, but may be removed by coagulation.
17. Copper Sulfate - a blue, crystalline substance used to kill algae and other microorganisms in taste and odor control. Sometimes called blue vitrol. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.
18. Copperas - a common name for ferrous sulfate. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.
19. Corrosion - the gradual deterioration, or destruction of, a substance or material by chemical action. Usually thought of as the oxidation or rusting of iron.
20. Ferric Hydroxide - the floc formed by the normal reaction between one of the iron coagulants and the alkalinity of a water in the coagulation process. $\text{Fe}(\text{OH})_3$.
21. Hardness - a characteristic of water, chiefly due to the existence therein of the carbonates and sulfates and, occasionally the nitrates and chlorides, of calcium, iron magnesium, which causes "curdling" of the water when soap is used, an increased consumption of soap, the deposition of scale in boilers, injurious effects in some industrial processes and sometimes objectionable taste in the water. It is commonly computed from the amounts of calcium and magnesium in the water and expressed as equivalent calcium carbonate.
22. Hardness, Carbonate - the carbonate and bicarbonate salts of calcium and magnesium. Approximately the same as temporary hardness.
23. Hardness, Non-carbonate - any salts of calcium and magnesium except carbonates or bicarbonates, usually sulfates or chlorides. Approximately the same as permanent hardness.
24. Ion Exchange - a process whereby water is passed through a granular material and ions of the granular material are replaced by ions contained in the water. For example, in the zeolite softening process the sodium ions (Na^+) of the

granular zeolite are replaced by the calcium ions (Ca^{++}) in the water to leave the water free of calcium, the cause of hardness, but containing an equivalent amount of sodium.

25. Lime - either calcium oxide, CaO , also called unslaked lime, or calcium hydroxide, $\text{Ca}(\text{OH})_2$, also called slaked lime. Used for the removal of carbonate or temporary hardness, and for pH control.
26. Lime-Soda Ash Softening - a process of softening water by adding lime to precipitate carbonate hardness and soda ash to precipitate non-carbonate hardness, with subsequent removal of precipitate by sedimentation and filtration.
27. Organic - (1) characteristic of, pertaining to, or derived from living organisms. (2) pertaining to a class of chemical compounds containing carbon.
28. Parts Per Million - parts, by weight, in a million parts, also by weight, of solution. Grams per million grams, pounds per million pounds, milligrams per liter are typical illustrations.
29. Quicklime - a calcined material, the major part of which is calcium oxide or calcium oxide in natural association with a lesser amount of magnesium oxide, capable of being slaked with water. Unslaked lime.
30. Soda Ash - a common name for sodium carbonate. Na_2CO_3 . Used to remove non-carbonate or permanent hardness and for alkalinity or pH adjustment.
31. Sodium Silicofluoride - a chemical sometimes added to water as the source of the fluoride ion, for the prevention of dental caries.
32. Softening - the process of removing from water certain mineral substances, principally calcium and magnesium compounds, which are the cause of hardness of water.
33. Tuberculation - a condition which develops on the interior of pipe lines due to corrosive material present in the water passing through the pipe and which results in the creation of small, more or less hemispherical lumps (tubercles) on the walls of the pipe, which increase the friction loss, and, by reducing the velocity, also reduce the capacity of the pipe.
34. Unit Operation - physical processes, i.e. mixing, sedimentation, flocculation, filtration, screening, etc.

35. Unit Process - chemical or biological processes, i.e. coagulation, disinfection, oxidation, adsorption, etc.
36. Zeolite - a chemical compound so imperfectly bound together that its composition will change in accordance with the concentration of chemicals in solution. Zeolites are used in water-softening processes.

B. Conversion Factors:

1. Conversion Table

MULTIPLY BY

TO GET	ppm	mg/l	gm/l	grains per gallon (gpg)	Kilogram per Cubic Foot (kcf)
ppm	-	1	0.001	0.0583	0.004
mg/l	1	-	0.001	0.0583	0.004
gm/l	1000	1000	-	58.3	0.436
gpg	17.1	17.1	0.017	-	0.0075
kcf	2294	2294	2.294	134	-

2. Pressure: inches of mercury $\times 1.13$ = feet of water
 lbs/sq inch $\times 2.31$ = head in feet of water

3. Flow: mgd $\times 1.55$ = cfs
 cfs $\times 449$ = gal/min
 gal/min = 695 $\times$ mgd

4. Volume: gallons $\times 3.78$ = liters
 gallons = 7.48 $\times$ cubic feet
 gallons of water $\times 8.34$ = pounds

5. Weight: pounds $\times 454$ = grams
 pounds $\times 7000$ = grams

C. Process - Operation Chain:

COAGULATION-FLOCCULATION

1. Purpose:

Removal of turbidity or color causing substances which are too small to settle in a reasonable time but too large to be in true solution.

2. Definition:

Coagulation - The reaction that occurs upon the addition of a coagulant to water to collect the suspended particles into agglomerates.

Flocculation - The action of bringing these small agglomerates together to build floc particles that are large enough and heavy enough to settle from the water.

3. Theory:

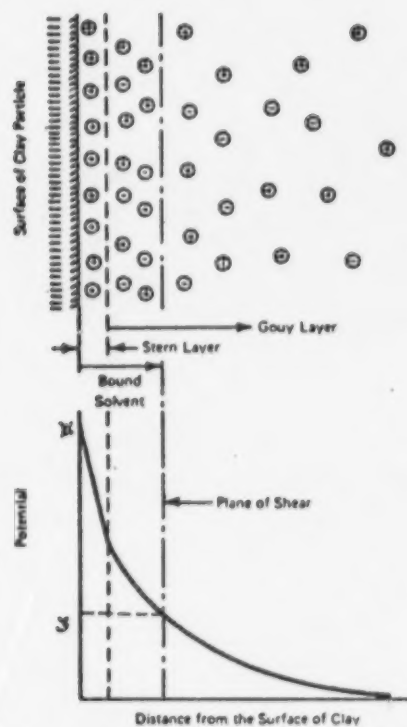
a. Colloidal Particle Characteristics.

(1) Size

(2) Surface Area

b. Stabilizing Forces.

(1) Charge on the Particles



The Structure of the Stern-Gouy Double Layer and the Corresponding Potentials

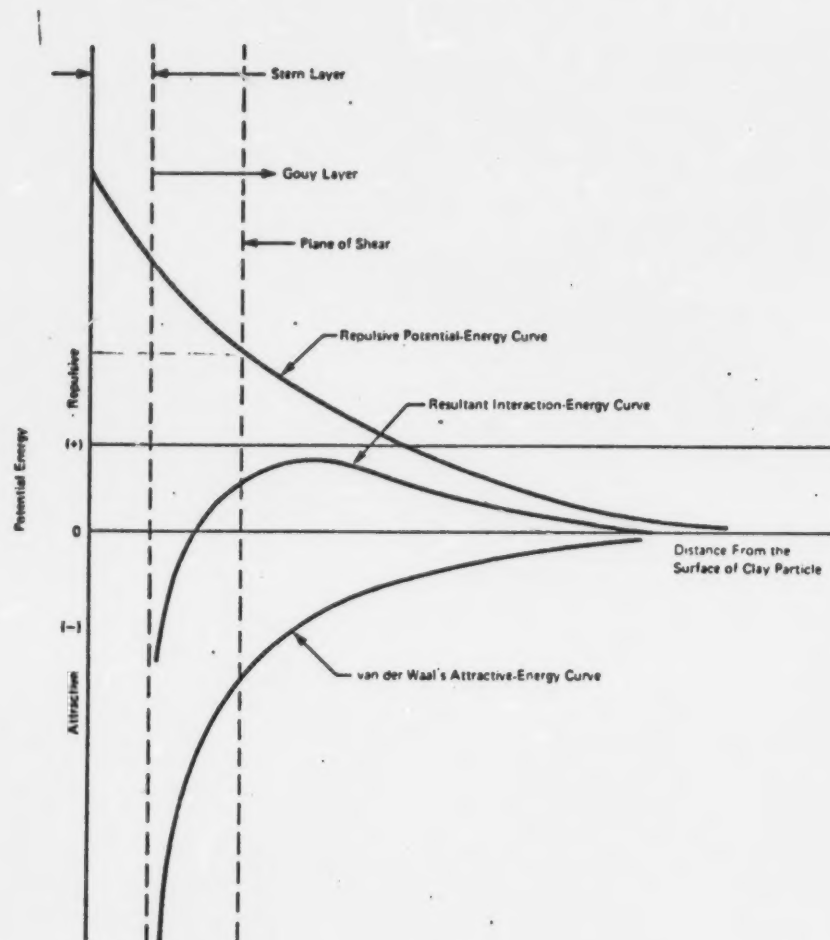
(2) Hydration

c. Destabilizing Forces.

(1) Brownian Movement

(2) Van der Waal Forces

$$\propto 1/d^5$$



Potential Energy of Interaction of Colloidal Particles

d. Mechanism of Coagulation.

Compression of the double layer in order to allow the particles to approach each other closely enough so that the Van der Waal forces can hold them together.

4. Factors Influencing Coagulation:

a. Water Quality.

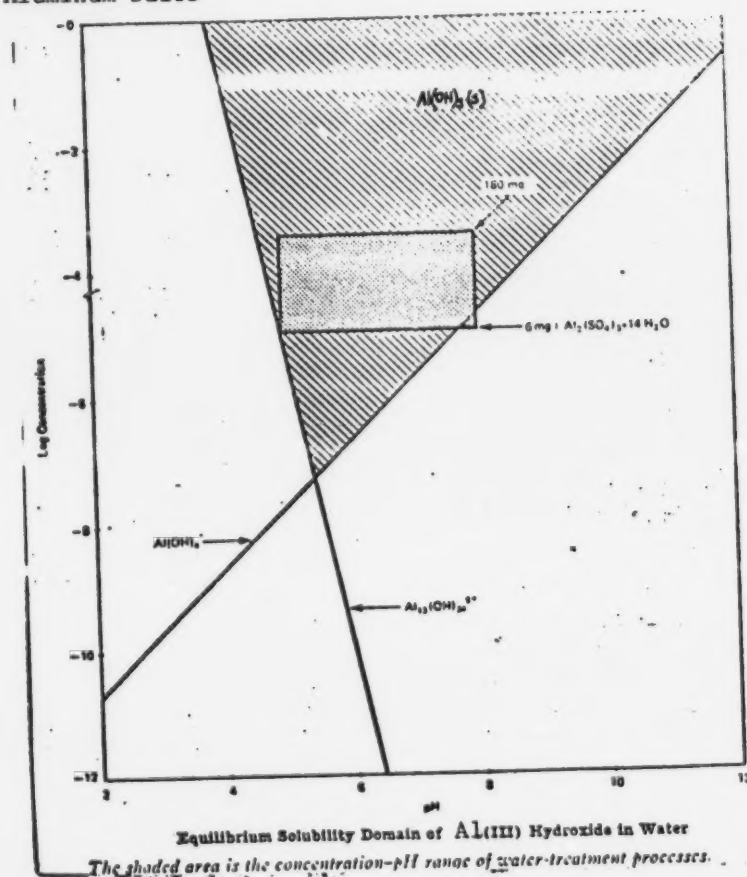
(1) pH

(2) Alkalinity

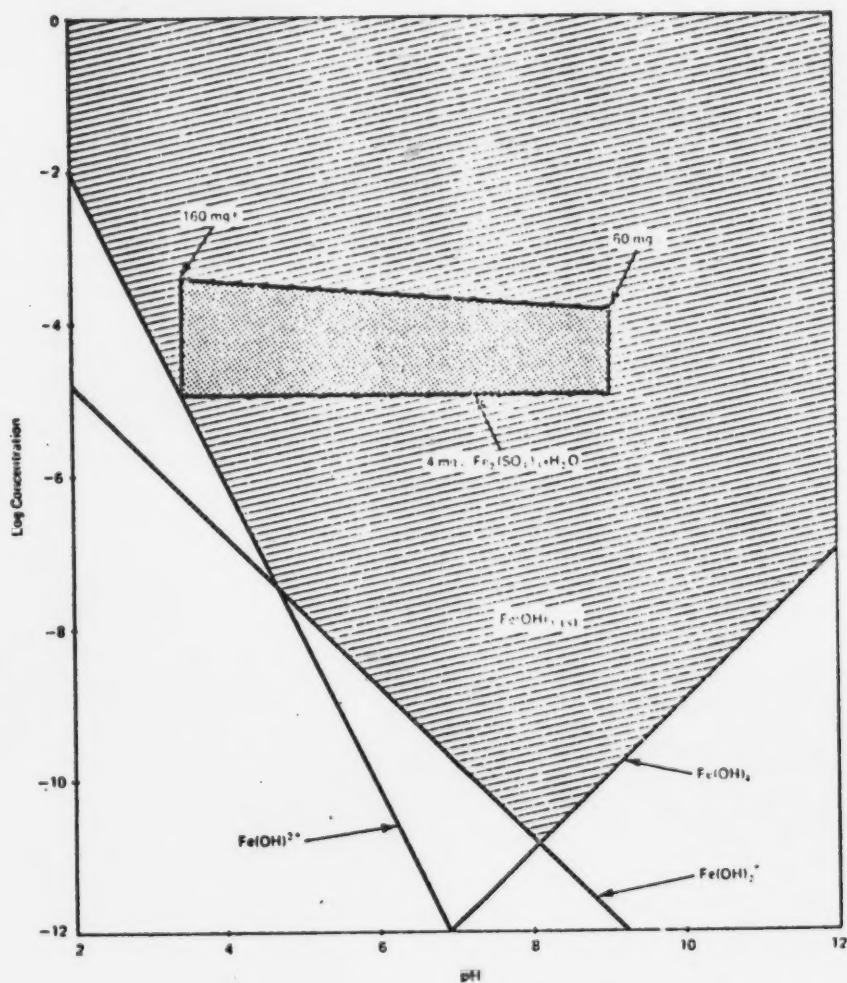
(3) Nature of Turbidity

b. Coagulant.

(1) Aluminum Salts



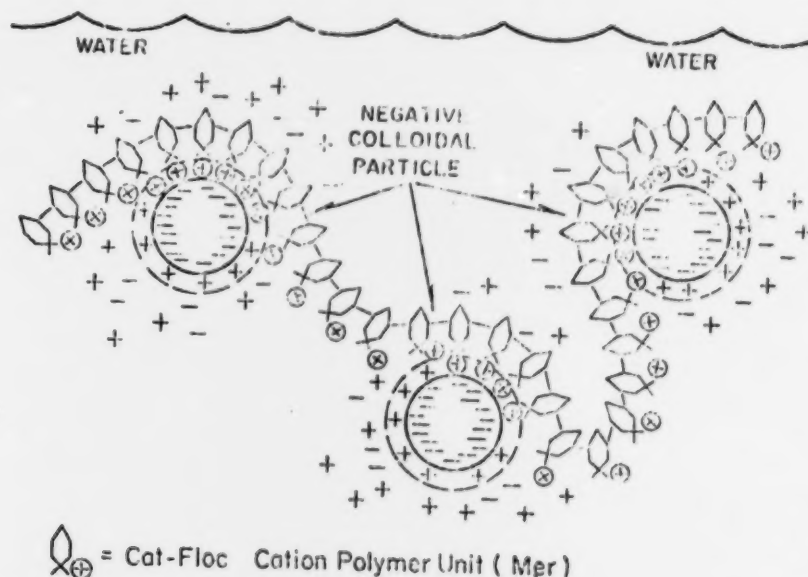
(2) Iron Salts



Equilibrium Solubility Domain of Iron Hydroxide in Water
The shaded area is the concentration-pH range of water-treatment processes.

5. Coagulant-Flocculant Aids:

a. Polyelectrolytes



Drawing illustrating the coagulation-flocculation reaction produced by Cat-Floc

b. Absorbants - Weighing Agents

c. Activated Silica

6. Process Control:

- a. Jar Test: Attempts to simulate plant conditions of mixing, coagulation and flocculation on a laboratory scale.

(1) Procedure

(2) Quantitative Measurements

- b. Zeta Potential: Employs a microscope to determine the rate of movement of the colloidal particles under the influence of an imposed potential difference.

(1) Zeta Potential
$$ZP = \frac{4 \pi \eta V}{HD}$$

η - Viscosity
V - Particle velocity
H - Potential gradient
D - Dielectric constant of water

(2) Particle Mobility is Directly Measured
$$\mu = \frac{dx}{tIR}$$

μ - Mobility, microns/sec/volt/cm
d - Distance traversed, cm
t - Time, sec
x - Cross-sectional area of cell, cm²
I - Current, amperes
R - Specific resistance, ohm-cm

- (3) ZP, ϕ (potential on particle modified by counter ions within the shear boundary)

- (4) ZP - Colloidal Impurity: 80 - 100mv
- Destabilized Colloid: 0 $\pm$ 5mv

- c. Pilot Filter: Small sample of plant mix water is continuously filtered through a small filter with effluent turbidity monitoring.

SEDIMENTATION

1. Theory:

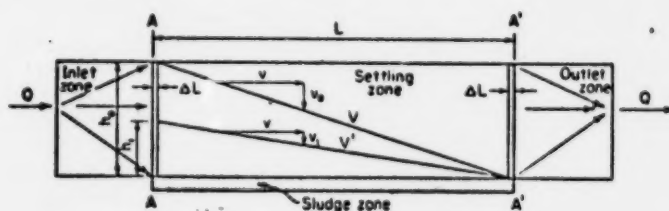
a. Stokes Law.

$$\text{Settling Velocity } V = \frac{g(\rho_s - \rho)d^2}{18\mu}$$

Where

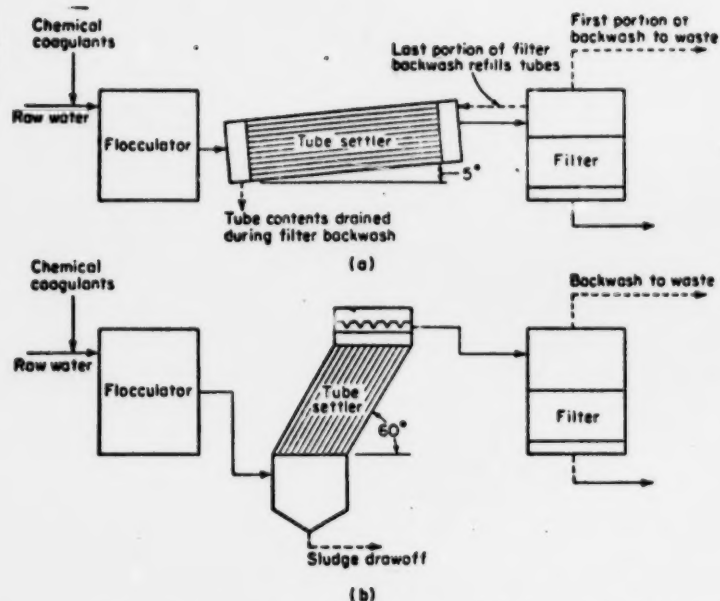
- g - Gravity constant
- ρ_s - Density of particle
- ρ - Density of water
- d - Diameter of particle
- μ - Viscosity of water

b. Ideal Sedimentation Basin.



c. Basin Characteristics.

- (1) Depth
- (2) Inlet arrangement
- (3) Baffles
- (4) Tube settlers



Basic tube-settler configurations. (a) Essentially horizontal. (b) Steeply inclined. (After Culp.)

(5) Outlet arrangements

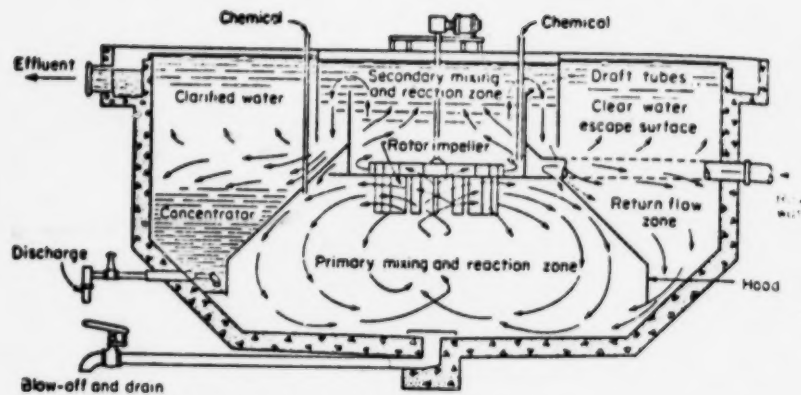
(a) Types

(b) Weir overflow rates

d. Detention Time.

e. Sludge Storage and Removal.

f. Solids Contact Clarifiers.



An accelerator, combining chemical mixing, reaction, floc concentration, and clarification. (By permission of Infilco.)

FILTRATION

1. Purpose:

Removal of suspended matter in the applied water; particle sizes to be removed.

<u>Material</u>	<u>Size (Millimicrons)</u> <u>(10^{-6} mm)</u>
Silt	50,000
Bacteria	5,000
Viruses	50
Colloids	1-1000

2. Types of Filters:

- a. Cake Filtration--removal at surface.
- b. Depth Filtration--removal occurs with depth.

(1) Slow Sand Filters:

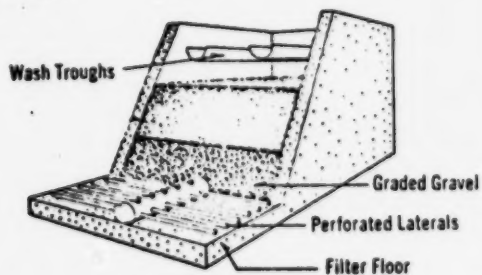
Rate - 0.05 gpm/sf; schmutzdecke on surface;
no pre-treatment required; large head loss.

(2) Rapid Sand Filtration:

Rate - 2 gpm/sf; backwashed; head loss control.

3. RSF Media and Construction:

a. Construction



b. Media

Properties of Filter Media Materials

Material	Shape	Density	Hardness*	Porosity, %	Range of effective sizes used, mm
Silica sand	Rounded	2.6	7	42	0.4-1.0
Silica sand	Rough	2.6	7	44	0.4-1.0
Crushed quartz	Angular	2.6	7	53	0.4-1.0
Silica gravel	Rounded	2.6	7	40	1.0-50
Garnet sand		3.1-4.3	6.5-7.5		0.2-0.4
Crushed anthracite	Angular	1.5	3	55	0.4-1.4
Alluvial anthracite	Rounded	1.5	3	50	0.4-1.0

*Moh scale.

4. Pre-Treatment Effects:

a. Flocculation-Sedimentation

b. Floc Strength

Floc strength	Condition
Very weak	Breakthrough begins when the filter sand head loss is less than 2 ft of water
Weak	Turbid effluent begins after head loss reaches 2 ft but before 8 ft of water
Medium	No breakthrough, but penetration of floc into bed greater than 3 in.
Strong	Penetration of floc into bed less than 3 in.

5. Mechanisms of Removal:

a. Straining

b. Sedimentation

c. Flocculation

d. Impingement

e. Chemical

f. Biological

6. Variables in the Process:

a. $C_e = f(V, d^3, p^4, \frac{H}{L}, Co, S)$

C_e - Concentration of ss in filtered water.

V - Filtration rate.

d - Effective size of media.

p - Porosity of media.

H - Terminal head loss.

L - Depth of penetration.

Co - Concentration of ss in applied water.

S - Surge amplitude.

b. $T = f\left(\frac{d^2 p^4 HSL}{V^{1.5} Co}\right)$

T - Length of filter run.

7. Filter Operation:

a. Filtration Rate - 2 gpm/SF

b. High Rate - 6 to 8 gpm/SF

c. Rate of flow control

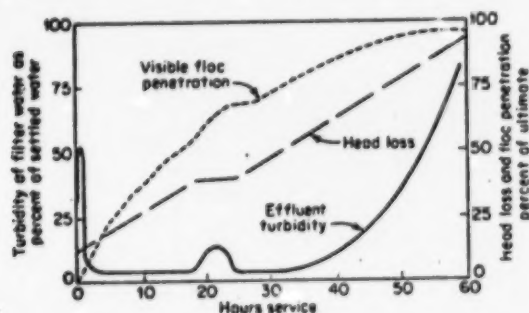
d. Head loss control (declining rate)

e. Filter aid - polymers

8. Operational Control:

a. Head loss

b. Turbidity - sight well or turbidimeter



Behavior of filter during filter run.

9. Backwash Filters:

a. Backwash Rate - 15 gpm/sf

b. Expansion - 50%

$$\% \text{ Expansion} = \frac{D_e - D}{D}$$

D_e - Depth of expanded bed.

D - Depth of bed.

c. Increased agitation

(1) Surface (Palamer) sweeps.

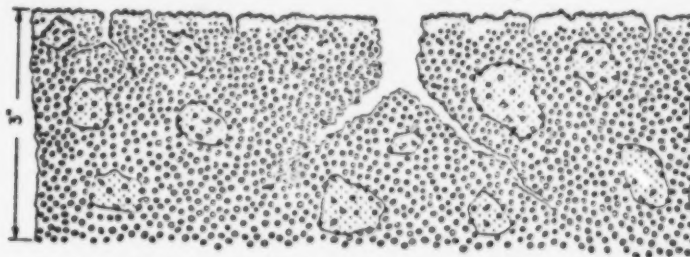
(2) Air agitation.

(3) Mechanical devices.

d. Control of backwash

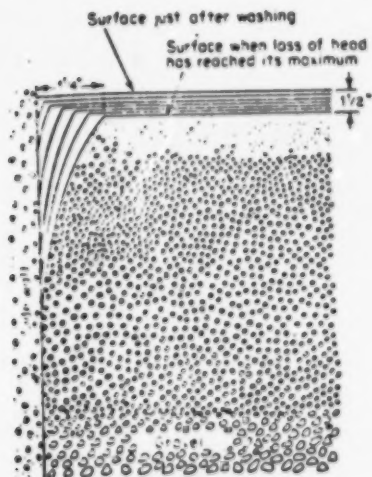
10. Operating Problems:

- a. Mud Balls - improper backwashing
- b. Sand Growth - improper backwashing
- c. Bed Shrinkage - improper backwashing



Sketch showing typical surface cracks in top 3 in. of filter beds.

- d. Pulling Away from Sidewalls - improper backwashing



Cracks along sidewalls
of filters.

c. Boils - broken underdrain

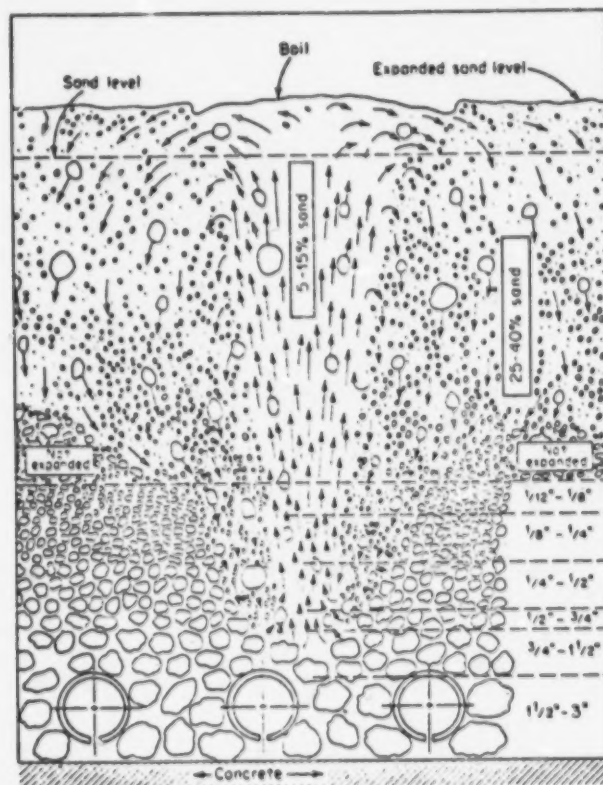
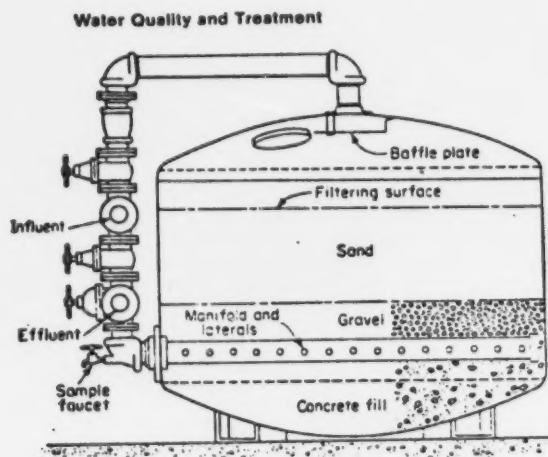


Diagram of sand boil in filter bed.

f. Air Binding

11. Other Types of Filters:

a. Pressure Filters



Cross section of typical pressure filter.

b. Diatomaceous Earth

c. Multimedia Bed

d. Upflow

e. Submerged

IRON AND MANGANESE REMOVAL

1. Effects of Iron and Manganese on Water Use.

- a. Color and Turbidity
- b. Staining Characteristics
- c. Microbial Growths
- d. Taste

2. Methods of Removal:

a. Precipitation and Filtration--Aeration

(1) Theory of Aeration.

- (a) Characteristics of volatile material
- (b) Temperature
- (c) Gas transfer resistance
- (d) Partial pressure of gases
- (e) Area - volume ratio
- (f) Time of exposure

(2) Types of Aerators.

(a) Spray aerators

(b) Multiple tray aerators

(c) Diffusion aerators

b. Precipitation and Filtration--Oxidation

(1) Oxidants.

(a) Chlorine

(b) Chlorine dioxide

(c) Potassium permanganate

(2) pH Effects.

c. Ion-Exchange--Manganese Zeolite

(1) Reactions.

(2) Regeneration

(4) Continuous feed

(5) Dosage

d. Stabilization

(1) Mechanism: To maintain a colloidal solution by keeping oxidized particles dispersed.

(2) Dosage.

TASTE AND ODOR CONTROL

1. Measurement - Threshold Odor Test.

2. Causes:

a. Inorganics - ppm

(1) Metals

(2) Sodium

b. Organics - ppb

¹² Concentration of Some Chemicals Causing Taste and Odor

Substance	Concentration detectable, ppb
Formaldehyde	50,000
Picolines	500-1,000
Phenolics	250-4,000
Xylenes	300-1,000
Refinery hydrocarbons	25-50
Petrochemical waste	15-100
Phenylether	13
Chlorinated phenolics	1-100

¹⁰ Threshold Odor Concentration (TOC) of Some Individual Compounds

Compound	TOC, ppb
Naphthalene	6.8
Tetralin	18
2-Methyl-5-ethylpyridine	19
Styrene	37
Acetophenone	65
Ethylbenzene	140
Bis(2-chloroisopropyl)ether	200
2-Ethylhexanol	270
Bis(2-chloroethyl)ether	360
Di-isobutyl carbinol	1,300
Phenylmethyl carbinol	1,450

c. **Biologicals.**

(1) **Algae**

(2) **Actinomycetes**

(3) **Nematodes**

3. **Destruction of Odor - Oxidation:**

a. **Oxidizing Agents - Any substances that can add electrons.**

(1) **Chlorine - Cl_2**

(2) **Chlorine Dioxide - ClO_2**

(3) **Ozone - O_3**

(4) **Potassium Permanganate - KMnO_4**

4. **Removal of Odor:**

a. **Conventional Unit Processes.**

(1) **Aeration**

--EFFECT OF AERATION ON THE THRESHOLD ODOR NUMBER AT SEVERAL CITIES			
Before Aeration		After Aeration	
Type Odor	Threshold Odor No.	Type Odor	Threshold Odor No.
Hydrogen sulfide	4	Hydrogen sulfide	2
Mine waste, sewage	30	Mine waste, sewage	22
Musty, grassy	22	Musty, grassy	22
Grassy, musty, fishy	22	Grassy, musty, fishy	22
Grassy, musty	30	Grassy, musty	30

(2) Coagulation-Flocculation

-EFFECT OF COAGULATION AND SEDIMENTATION ON THE THRESHOLD ODOR NUMBER AT SEVERAL WATER PLANTS				
Coagulant Used	Before Coagulation and Sedimentation		After Coagulation and Sedimentation	
	Type Odor	Threshold Odor No.	Type Odor	Threshold Odor No.
Alum	Mine waste, sewage	23	Mine waste, sewage	16
Alum	Musty	4	Musty	4
Alum	Musty	7	Musty	7
Alum	Musty-fishy	14	Musty-fishy	10
Ferric Sulfate	Musty, oil refinery	14	Musty, oil refinery	14
Alum	Musty	10	Musty, septic	16
Alum	Musty	3.5	Musty, septic	19
Ferrisul	Musty, brackish	220	Musty, brackish	150
Alum	Musty, brackish	220	Musty, brackish	200
Alum	Musty, woody, sewage	18	Musty, woody, sewage	18
Alum	Musty, woody, grassy	40	Musty, woody, grassy	40

(3) Filtration

-EFFECT OF FILTRATION ON THE THRESHOLD ODOR NUMBER AT SEVERAL WATER PLANTS			
<i>Rapid Sand Filtration</i>			
Before Filtration		After Filtration	
Type Odor	Threshold Odor No.	Type Odor	Threshold Odor No.
Musty	5.6	Musty	3.2
Musty	7.5	Rotten	10.0
Oily	10.0	Oily	5.6
Grassy	1.8	Grassy	-
Chlorinous	16	Chlorinous	16
Lime, musty	16	Lime	11.5
Chlorinous, musty	31	Chlorinous	22

b. Adsorption - Activated Carbon.

(1) Theory - Physical Process.

(a) Porous Structure

(b) Van der Waals Forces

(2) Manufacture.

(a) Sources

(b) Process - Dehydration, Carbonization, Activation

(3) Types.

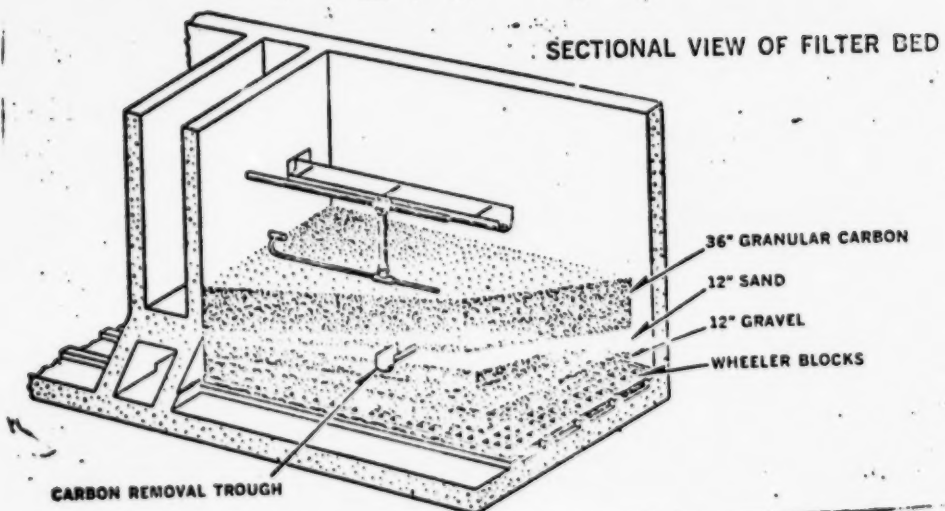
(a) Powdered

1. Point of Application

2. Dosage and Control

(b) Granular Beds

1. Installation



2. Life

3. Case Histories

5. Prevention of Taste and Odor Problems - Algae Control:

a. Copper Sulfate CuSO_4

- (1) Application
- (2) Effectiveness

b. Carbon Blackout

- (1) Prevention or Control
- (2) Application

SOFTENING

1. Hardness:

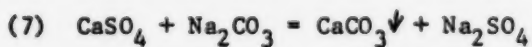
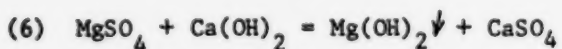
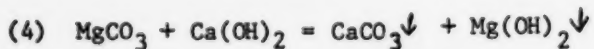
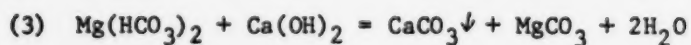
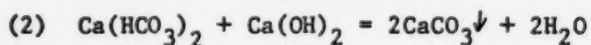
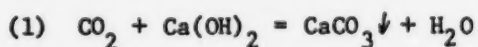
a. Definition

b. Carbonate Hardness

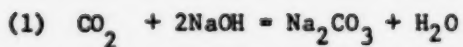
c. Noncarbonate Hardness

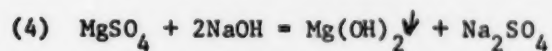
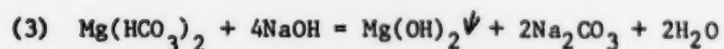
2. Chemistry of Softening :

a. Lime - soda ash



b. Caustic Soda





3. Variations in the Lime-Soda Process:

a. Conventional Lime-soda Process Followed by Recarbonation

b. Excess Lime Treatment

c. Excess Lime Followed by Recarbonation

d. Split Treatment

e. Three-stage Treatment

4. Benefits of Lime Softening:

5. Disposal of Lime-softening Sludges:

6. Equipment Required for Lime-soda Ash Softening:

a. Rapid-mix Basin

b. Flocculation Basin

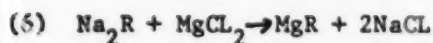
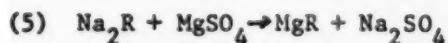
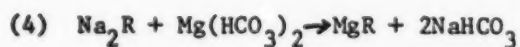
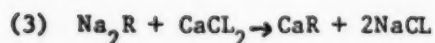
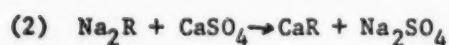
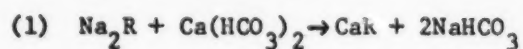
- c. Sedimentation Basin
- d. Chemical Feeders
- e. Filters and Appurtenances
- f. Sludge Handling Pumps

7. Recarbonation:

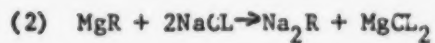
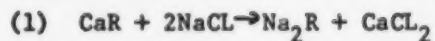
- a. Chemistry
- b. Equipment

8. Ion-Exchange Softening:

- a. Sodium Cation Exchangers
- b. Ion-Exchange Softening



c. Regeneration



d. Cation Exchangers

e. The Softening-Regeneration Cycle

f. Performance Characteristics of Cation Exchangers

- (1) Rate of Flow in GPM/ft^2 vs. gpm/ft^3
- (2) Effect of Salt Dosage on Exchanger Capacity
- (3) Effect of Brine Concentration on Exchanger Capacity
- (4) Brine Reclamation
- (5) Effect of Brine Contact Time on Exchanger Capacity
- (6) Effect of Bed Depth on Exchanger Capacity
- (7) Effect of Water Composition on Softener Performance
- (8) Effect of Service Flow Rate Capacity
- (9) Effect of Temperature on Performance
- (10) Backwash Flow Rate

g. Limitations

- (1) Iron, Manganese and Aluminum
- (2) Turbidity and Bacterial Slimes
- (3) Oxidizing Agents
- (4) Temperature
- (5) pH

9. Design of Softening Equipment:

a. Equipment Size $E = \frac{KQH}{G}$

Where: E = Volume of exchange material to be used (ft³)
Q = Volume of water to be treated between regenerations (ft³)
H = Hardness of water (grains/gal)
G = Hardness to be removed between regenerations per unit of
volume of exchange material (grains/ft³)
K = A factor depending on the units (7.48)

b. Construction Details

- (1) Shells
- (2) Underdrain System
- (3) Gravel
- (4) Ion-Exchange Bed
- (5) Service Water Inlet and Washwater Collector
- (6) Brine Inlet System

c. Operational Controls

- (1) Backwash
- (2) Rinse
- (3) Meters
- (4) Gravity Softeners
- (5) Brine and Wet-Salt Storage Tanks

d. Disposal of Spent Brine

- (1) Evaporation Ponds
- (2) Uncontrolled Dilution
- (3) Controlled Dilution
- (4) Brine-Disposal Wells
- (5) Ocean Disposal

FLUORIDATION

PUBLIC HEALTH ASPECTS

WHAT IS FLUORIDATION?

Fluoridation is the deliberate adjustment of the fluoride content of public water supplies to a level of approximately one part per million of fluoride for the purpose of reducing tooth decay. Some 10 million Americans have a naturally fluoridated water supply, and in the past twenty-five years over 4,000 communities have adjusted the fluoride content of their water.

Fluorine is the 17th most abundant element in the earth's crust. It is present in all parts of the environment—in the food, water and air, and is thus a normal constituent of all diets. Fluoridation, then, may be viewed in another way as the redistribution of a natural trace element by means of water works engineers in accordance with scientific and medical guidelines to achieve optimal levels.

THE EXTENT OF THE DENTAL CARIES PROBLEM

A Incidence

Approximately 95% of those reaching adulthood in our country have evidence of caries. Large studies have revealed that the average American has 11 decayed teeth by age 15. Half of the population over 55 years of age have no natural teeth whatsoever. The caries lesions increase progressively in size and without treatment can lead to considerable suffering, loss of teeth and infection, which can be the source of serious systemic disease.

B Cost

In 1964, 3 billion dollars were spent in the United States for dental care, one-twelfth of the total expenditure for health care. With a concentration of 1 ppm of fluoride in the drinking water there is a 60% reduction in rate of tooth decay in children up to age 16. It has been estimated that fluoridated water systems, if available throughout the country, could in time reduce the national dental bill by one-half. The benefits expected from fluoridation then are considerable.

ORIGIN OF FLUORIDATION

In 1901 research was begun to find the cause of a progressive decoloration of the teeth (fluorosis). By the early 1930's the causative agent was identified as fluorides in the water supply. It was observed, however, that these mottled teeth were resistant to cavities and there followed a number of epidemiological studies which established the protective effect against caries of drinking water containing approximately 1 ppm of fluoride.

SUPPORT FOR FLUORIDATION - THE NEWBURGH KINGSTON STUDY AND RELATED RESEARCH

A The Newburgh Kingston Study

During 1954-55 a study of dental health was carried out in Kingston, New York, which has non-fluoridated water, and nearby Newburgh, New York, which had been fluoridating the water a 1ppm since 1945. The children of the two communities were studied by age group. It was noted there were fewer decayed, missing or filled (DMF) teeth in all age groups of children from Newburgh compared to Kingston, the greatest benefit to children 6-9 years of age (57% fewer DMF teeth.) The proportion of children in the 6-9 year old group with all twelve primary teeth present and free of caries was over 5 times higher in the fluoride community than in the non-fluoride community.

B Aurora-Rockford Study

This involved the comparison of 18 and 19 year olds on lifetime consumption of natural optimum and low fluoride water. Young adults from Aurora (with natural optimum fluoride water) had approximately one-half the decayed teeth per person (.45 vs .96) and approximately one-half the DMF teeth per person (6.12 vs 11.90). Percentage of persons caries free was 12.5% in Aurora vs. 0.0% in Rockford.

C The Philadelphia Experience

The water supply system in Philadelphia was fluoridated in 1954 with an optimum level of 1 ppm. The effectiveness of the program was evaluated in 1964 using data collected annually by the dental examiners of the Board of Education (school children have been given dental examinations during selected grades of school since 1948 in order to determine status and needs of dental health). Evaluation of this data shows that in 1954, before fluoridation, there was approximately 1 DMF tooth for every 2 six-year olds; in 1961 the ratio was 1 DMF tooth for every 10 six-year olds, a 77% reduction in dental caries in the group who had received full benefit of fluoridation.

MEDICAL ASPECTS OF FLUORIDATION

A Causes of Dental Caries

Tooth decay appears to be caused by civilization; when natural foods are replaced by processed foods, an increase in dental caries follows. There is now general agreement that tooth decay is of bacterial origin and that sugar must be present for bacteria to grow; adequate intake of vitamins and proteins and good oral hygiene are of great importance in preventing cavities. With the ingestion of adequate amounts of fluoride ion, the teeth are more resistant to bacterial action and fluoride promotes a resistance to dental caries beyond that afforded by adequate diet and oral hygiene. The benefits of fluoride in the water are most marked during the process of tooth development - during this period of calcification of the crown of the tooth and through the period of eruption. Resistance to decay continues throughout life, particularly for those who continue to drink fluoridated water.

B Fluorosis and Osteofluorosis

Fluorosis, or mottling of the teeth, can occur in some children who consume water containing 2 ppm fluoride during the first eight years of life; the severity of the mottling seems to bear a quantitative relationship to the fluoride level in drinking water, though regional climatic conditions influence water consumption and hence total fluoride ingested. It may occur in approximately 20%.

Osteofluorosis refers to the deposition of fluoride in the skeletal system which occurs at levels in the drinking water

usually above 8 ppm; this may be seen in 10% of a population so exposed. Increased bone density is seen on X-ray and it is only at very high levels that symptoms of illness appear.

THE CONTROVERSY OF FLUORIDATION

A Nature and Extent of the Scientific Consensus

Fluorine, from which fluoride ions are derived, is a dangerous element, and fluoride compounds themselves are sold as commercial poisons for rodent extermination. These facts have produced considerable confusion and have at times precluded rational discussion of fluorides usefulness in the reduction of dental caries.

The biological effects of fluorides have been described in over 3,000 clinical and experimental reports in the last 30 years and includes contributions of scientists of all disciplines - biologists, chemists, dentists, physicians, and toxicologists. This research, like any research, is not free of scientific controversy; however, the overwhelming evidence indicates both the efficacy and safety of fluoridation. It has been supported by the Public Health Service, the American Dental Association, the American Medical Association, the World Health Organization and many others.

B Nature of the Opposition

There are three basic arguments raised against the introduction of fluoride compounds into the public water supply. First, anti-fluoridationists deny the effectiveness of fluoridation in preventing caries and stress the alleged disfiguring effects. The justification for fluoridation rests on statistics gathered in public health experiments and they challenge the validity of these data. The impressive thing is the large number of studies that have repeatedly demonstrated the value of fluoridation and it now seems that this argument is difficult to support.

Second, anti-fluoridationists stress health dangers involved in the use of mass fluoridation, ailments ranging from cancer to left handedness. However, mortality data from studies in Illinois, Michigan and Wisconsin demonstrate that there is no significant difference in risk of death from specific diseases such as heart disease, cancer, nephritis or diabetes. Nowhere in reports is there any evidence to support that the addition of fluoride to the drinking water increased the incidence of any

disease or indeed had any effect on health of the people except for the benefit to the childrens's teeth.

Third, antifuoridationists argue that fluoridation is a mass medication that infringes upon constitutionally protected rights of individual liberty and religious

freedom. These arguments are similar to those which preceeded vaccinations against small pox, chlorination of the water and pasteurization of the milk. Although fluoridation has been challenged in the courts many times, it has been upheld in all final decisions. The court has supported the stand that fluoridation is a prudent public health policy.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE

NATIONAL INSTITUTES OF HEALTH

Refer: PPB-29
July 1971

\$100,000 SO-CALLED REWARD OFFER -- A GIMMICK

For years a so-called reward offer has been circulated by the opponents of fluoridation. The fact that the reward has not been collected has been used by them as substantiating their claims. Recently, a flyer has appeared in which the reward has been increased. The clever wording of this reward offer clearly exposes it to be an uncollectible gimmick. Examples of its inherent fallacies follow:

- (1) The wording asks proof that fluoridation "will cause no future body harms." This would require proof of events which will take place in the future, which is impossible.
- (2) The wording asks that, using PHS recommended fluoride levels (approx. 1 ppm), proof be given that "poisonous" fluorides are safe. Fluorides at PHS recommended levels are not poisonous, and proof of effectiveness and safety at such levels would be irrelevant to use at the much higher levels at which fluoride could be termed "poisonous."
- (3) The so-called reward offer is ambiguous, with no indication of what would be considered a "controlled" experiment, what proof would be considered acceptable, or who would make the decision as to whether the proof was acceptable.
- (4) The flyer requires the posting of a bond by anyone attempting to collect the reward to cover any costs which the offerors of the reward might incur if the proof is deemed invalid; this condition would be extremely difficult to comply with, for the amount of such possible costs would appear to be impossible to determine in advance. Moreover, in view of the difficulties and ambiguities in the nature and wording of the offer which are pointed out above, a person seeking to collect the reward could easily be placed in an impossible economic position.
- (5) Posting of the bond, above, could make payment of the reward unenforceable, because the entire offer might be considered a wager, and the courts will not enforce the collection of a gambling debt.

Page 2

It is clear, therefore, that the so-called reward is a gimmick that serves to confuse and deter action on a proven public health measure. If after a quarter-century of demonstration of the use of fluoridation at Public Health Service recommended levels, with no clinically substantiated evidence of any bad or harmful effects from drinking such water, opponents still question the safety and effectiveness of fluoridation, it would appear that no evidence could ever be acceptable to them.

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service

National Institutes of Health

Refer: PPB-33
January 1972

ESSENTIALITY OF FLUORINE

At the 138th meeting of the American Association for the Advancement of Science, Klaus Schwarz, M.D., reported on "Trace Elements Newly Identified as Essential to Animals (Fluorine as an Essential Element)." Dr. Schwarz is Chief, Laboratory of Experimental Metabolic Diseases, Medical Research Programs, Veterans' Administration Hospital, Long Beach, California, and Associate Professor, Department of Biological Chemistry, School of Medicine, University of California at Los Angeles. The discovery of the essentiality of fluorine was reported as the latest in a series of findings on indispensable trace elements in animals. Excerpts from Dr. Schwarz' paper follow:

The most recent result of systematic studies to identify new essential trace elements for mammals is the discovery that fluorine is an essential trace element. It is required for normal growth in the rat. Proof for an essential role of fluorine, normally supplied as fluoride, in growing animals was obtained in experiments carried out under rigidly controlled conditions in trace element sterile isolators. The rats were maintained on highly purified amino acid diets which contain all the known dietary agents in sufficient amounts. Under these conditions, supplements of 2.5 ppm (parts per million) of fluorine as potassium fluoride, stimulate growth by over 20%. The data are highly significant. Attempts to prove that fluorine is essential were made before, but under less carefully controlled conditions. The finding throws a new and different light on the use of fluoride. The element seems to be essential not only for the formation of teeth and bones -- in which it is normally contained in very high amounts (200-1,000 ppm) -- but appears of more general importance.

The project was carried out at the Laboratory of Experimental Metabolic Diseases, Medical Research Programs, VA Hospital, Long Beach, California under the auspices of UCLA, and with the financial support from the National Institutes of Health. Drs. J. C. Smith, Jr., E. Vinyard, and D. B. Milne contributed significantly to its success.

NOTE. -- Underscore supplied.

The most sensitive indicator for deficiencies was growth. Three elements, namely tin, vanadium, and fluorine, have been firmly identified as essential for growth, while another one, silicon, is currently under investigation.

The discovery of an essential need for fluorine was made possible by further improvements in the purity of the diets after tin and vanadium had been recognized as being indispensable. Tin and vanadium were included in the basal diet, and the fluorine content of the diet was reduced to below 0.5 ppm. The growth promoting effect of fluoride was seen consistently in ten successive experiments, each carried out over a four week interval. Dose levels of 1, 2.5 and 7.5 ppm of fluorine were supplemented in the form of potassium fluoride. One ppm gave a significant but incomplete result. 2.5 ppm fluoride produced optimal results, not different from those obtained with 7.5 ppm in the diet. 20-30% increases in growth rates were obtained.

Normal fluorine levels in teeth and bone can easily reach 700-1000 ppm, while the concentration of fluorine in blood plasma is very effectively controlled at 0.1-0.2 ppm even if large amounts of fluoride are given. Any excess is rapidly deposited in the bone or excreted through the urine. The normal fluorine levels in tissues such as liver, heart, and kidney are approximately 2-5 ppm (on a dry basis). These levels are maintained steadily even if high amounts of fluoride are supplied over extended periods of time. The amounts in these tissues are quite similar to those in many nutrients. Cereal and other grains contain 1-3 ppm, cow's milk usually 1-2 ppm (on a dry basis), raw and peeled potatoes 1-2 ppm of dry matter, while ocean fish are reported to supply 5-10 ppm. The importance of various fluoride levels in drinking water is well known. A peculiar situation is presented by tea in which fluorine concentrations of 100 ppm are common. It is fair to assume that with the increasing refinement of our staple foods attention should be paid to the fluorine intake of growing animals and children to guarantee that the large amounts of fluorine needed during growth are adequately supplied.

Each of the elements newly identified as essential opens up new facets in biochemistry, nutrition, and also medicine. Thus the bio-inorganic and -organic chemistry of tin, vanadium, and fluorine are largely new, unexplored territory. The application and usefulness of these trace elements in animal and human

nutrition can at this point only be surmised. Also the medical implications of these findings will have to be worked out in detail. However, it is expected some of the newly identified essential elements may be clinically important, similar to those which have been known for a long time.

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service

National Institutes of Health

Refer: PPB-48
November 1972

NUTRITIONIST EMPHASIZES NEED FOR FLUORIDE

Fluorides have come in for attention on more than one occasion recently in the newspaper column "Food for Thought." This column is written by Dr. Jean Mayer and distributed to about 100 newspapers by the Chicago Tribune-New York News Syndicate. Dr. Mayer has an extensive background in physiological chemistry and is a Professor of Nutrition at Harvard University. In 1969, he served as Chairman of the White House Conference on Food, Nutrition, and Health, and in 1971 as Chairman, Nutrition Division, White House Conference on Aging.

The following statements appeared in his August 1972 column:

Dental caries -- or cavities -- is our most common disease. It is the result of the interaction of many causes: inherited susceptibility, inadequate fluoride in the water, excessive sugar in the diet, poor nutrition, and poor dental hygiene.

* * * * *

Since there isn't anything you can do about your heredity, let's see what you can do. For one thing, you can pressure your local government to fluoridate your water supply (if it isn't naturally fluoridated). If your water has at least one part per million of fluoride, and if your children drink it, their teeth will be partly protected. Studies show that they will have only half as many cavities as children who don't get fluoridated water.

Excerpts from his October 1972 column on the need for trace minerals -- including fluoride -- are attached.

Division of Dental Health
Preventive Practices Branch
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Enclosure

Excerpts from column, "Food for Thought," by Dr. Jean Mayer,
October 1972.

These days most of us are aware that even the slightest interference with nature's processes can cause havoc far out of proportion to its apparent importance. Kill off one species of insect and entire crops can be devastated, for instance.

We're beginning to appreciate the same thing when it comes to the human diet. We know that we must have the "large" minerals such as calcium in order to be healthy. But we are also discovering that the tiniest traces of the minor minerals are also vital to life.

* * * * *

When I sat down to compile a list of the foods containing all the necessary microscopic amounts of these so-called trace minerals, the result was quite familiar: Liver, meat, fish and other sea foods, egg yolk, whole grains, green leafy vegetables, peas and beans, milk, fruits, iodized salt (if you don't eat seafood), tea, coffee, and fluoridated water. In other words, our old familiar balanced diet.

Let's see what the various vital trace elements are and why you need them. In some cases scientists haven't yet determined the precise amounts you need daily. We only know that they are involved in every single bodily process, from birth to reproduction to maintenance of good health in old age.

IRON is . . . one of the trace elements for which we have a definite daily recommended level: 10 milligrams a day for men and 18 for women . . .

There's even less ZINC than iron in our bodies but what there is, is needed . . .

COPPER, like iron, is needed to make red blood cells, but it's needed in much smaller amounts . . .

There's only the smallest amount of IODINE in our bodies, and it does only one thing -- but without it we couldn't live . . .

There's about as much MANGANESE in our bodies as a tiny chip off the end of a grain of rice. But we need manganese for the good health of the liver, kidneys, eyes, bones, and salivary glands . . .

COBALT is part of vitamin B12 . . .

The few milligrams of FLUORINE in our bodies is needed not only for solid tooth formation in children, but also to help retain calcium in our bones when we grow older. It is necessary for growth of animals. And if it isn't in your water supply it should come from supplements.

CHROMIUM, in amounts so tiny they can hardly be measured, is the most recently recognized required mineral . . .

. . . we have to stick with what we are sure about: That a balanced daily diet not only gives you the well-known nutrients you need, but also those mysterious -- and vital -- trace minerals.

LETTER TO THE EDITOR
BOSTON GLOBE (MORNING)
SEPTEMBER 8, 1973

Fluoride dangerous

Medical hazards of fluoridated water to consumers are being reported with increasing frequency by researchers throughout the world including scientists from the famed Mayo Clinic.

A recent article by Mayo Clinic physicians in the Nov. 13, 1972 issue of the Journal of the American Medical Assn., for instance, reported crippling bone changes in two young persons with kidney disease from fluoride in drinking water at or near the so-called safe concentration, and the death of one of them. At least four similar deaths are recorded in the US medical literature.

In a more recent report (July 16) another Mayo Clinic physician states that 11 of 12 patients exposed to fluoride for two years or more developed symptomatic bone disease with severe pain and rib fractures. In addition, two patients experienced extreme wasting, suggesting other poisonous effects of fluoride.

"We are convinced," the report concludes, "that fluoride is harmful in long-term dialysis." Another patient with fluoride poisoning caused by the use of freeze-dried tea is also under their treatment. Fluoride poisoning in habitual tea drinkers has been reported from England.

In view of these facts, Dr. William J. Bicknell, as Commissioner of Public Health, should immediately stop the addition of any fluoride chemical to the water systems of the MDC and other communities in Massachusetts or disprove the Mayo Clinic research. Entrusted with the health of all individuals he has no alternative.

PHILIP E. ZANFAGNA, MD
Lawrence

LETTER TO THE EDITOR
BOSTON GLOBE (EVENING)
NOVEMBER 6, 1973

Report misinterpreted

You published a letter to the Editor entitled "Fluoride dangerous," by Dr. Phillip Zanfagna. In it, he quoted reports from the Mayo Clinic about the supposed hazards of fluoridation.

As co-authors of these reports, and as Mayo Clinic physicians, we are dismayed by Dr. Zanfagna's interpretation of our research. Not only did he present the facts incorrectly, he drew inaccurate conclusions, to which we do not subscribe at all. According to Dr. Zanfagna, our two young patients with kidney disease had "crippling bone changes" from fluoride in their drinking water "at or near the so-called safe concentration."

In reality, these two patients had no clinical symptoms of bone disease whatsoever. Only their x-ray films showed evidence of fluoride effects. Both patients had their kidney disorders since birth. Their disease made them abnormally thirsty much of the time, so they drank extremely large quantities of water — which, in their community, happened to contain a high concentration of naturally occurring fluoride. Because their kidneys were unable to dispose of the fluoride as a normal person's do, some of the excess reached their bones. We wish to emphasize, however, that neither patient has experienced any bone symptoms. Furthermore, both are alive today and doing well, contrary to Dr. Zanfagna's statement that one died.

The doctor says that "another Mayo Clinic physician states that 11 of 12 patients exposed to fluoride for two years or more developed symptomatic bone disease with severe pain and rib fractures." What he failed to point out was that these patients had advanced kidney disease and that they were being treated with an artificial kidney machine, which uses water to remove waste materials from the blood — ordinar-

ly a function of normal kidneys. Although it was not recognized at the time, the use of fluoridated water in the artificial kidney resulted in excessive bone absorption of fluoride. And these patients did, indeed, have serious bone problems. However, this degree of absorption would be virtually impossible from drinking fluoridated water, even in patients with kidney disease. And since we discovered the problems created by using fluoridated water in the artificial kidney machine, we have advocated substituting specially treated fluoride-free water for this purpose.

Certainly, we never implied that fluoridated water is harmful to the general population. Our reports referred only to a very limited group of patients — those receiving special treatment for advanced kidney disease. For comparison, consider the patient with diabetes, who must limit the sugar in his diet. Or the kidney patient, who must cut down on the salt he uses. Even sugar and salt at certain levels can be harmful to some types of patients.

To give Globe readers an idea of Mayo Clinic's stand on fluoridation, members of our Department of Dentistry favor fluoridation of public water supplied. Moreover, since 1959 the board of governors of the Mayo Clinic has unanimously endorsed a program of fluoridation for Rochester, Minn. — the city where the Mayo Clinic is located and where essentially all of its staff physicians and employees reside.

WILLIAM J. JOHNSON, MD
JAMES V. DONADIO, JR., MD
JENIFER O. DOWSEY, D. PHIL.
Department of Internal Medicine,
Rochester, Minn.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service

Health Resources Administration

Refer: PPB-66
May 1974

MISREPRESENTATIONS OF NATIONAL RESEARCH
COUNCIL'S: FLUORIDES

The 1971 Report of the National Research Council, National Academy of Sciences, "Fluorides: Biologic Effects of Atmospheric Pollutants," has been variously referenced by opponents of fluoridation as allegedly questioning the safety and effectiveness of fluoridation for dental health.

The National Research Council (NRC), which has long endorsed fluoridation, has indicated that the information in their report, has been distorted and misrepresented. A statement to this effect, prepared by Dr. Jaroslav J. Vostal who was chairman of the NRC panel on fluorides, was released by the NRC on February 7, 1974, and appears below. (Dr. Vostal serves on the faculty of the Department of Pharmacology and Toxicity, University of Rochester School of Medicine and Dentistry, Rochester, New York.)

"During the past few months, and increasingly in recent weeks, letters to the editors in connection with the safety and usefulness of fluorides in drinking water have appeared in newspapers in several parts of the nation, citing a report of the National Academy of Sciences on Fluorides (1). Some of these letters contain common phraseology, as follows:

In 1971, the prestigious National Academy of Sciences published a review which substantiates the excessive contamination by fluorides in the environment, in humans, other animals and plants. It states that unequivocal evidence does not exist that fluoride prevents dental decay, or is essential to any animal or plant.

"The first sentence of the above quote is a clear distortion of the report prepared by a panel on which I served as chairman. Cases of fluoride contamination of the environment to the level that would constitute a danger to populations, animals or plants are relatively rare. Such as have occurred generally resulted from occupational exposures or were limited to particular areas closely adjacent to industrial processes or geological sources.

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- (1) Fluorides, NRC-NAS Report prepared by the panel on fluorides of the Committee on Biologic Effects of Atmospheric Pollutants with the intention to provide a scientific basis for air quality criteria document on airborne fluoride, 295 pp., National Academy of Sciences, Washington, D.C., 1971

"The second sentence of the quote appears to be incorrectly assembled from page 66 of the report, where it is stated:

Unequivocal evidence that fluorides perform any vital function in animals has not yet been produced. There is no doubt that an increase in the fluoride intake of the population in most parts of the world does result in a decrease in incidence of dental caries in that population. That in itself is no indication of fluorine essentiality, inasmuch as caries incidence depends on many factors, and many persons with perfectly sound dentition have had only minimal exposure to fluoride.

"On page 67 the report states further that:

. . . the beneficial effects of fluoride on dental health or bone metabolism should be considered as pharmacological responses, and not as a cure of pre-existing deficiency condition.

"A reasonable and correct paraphrase of these statements might be: Fluoride has without any doubt a beneficial pharmacological effect in preventing tooth decay, but this does not mean that the presence of fluoride in the diet is indispensable for any vital (i.e. important and useful) function, including the integrity of the dental system, in animals or man."

It should be noted that the comments on the essentiality of fluoride in the referenced NRC report were written prior to the publication of recently completed research that has confirmed the essentiality of fluoride for growth and reproduction (2).

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- (2) Schwarz, Klaus, and Milne, D. B.: "Fluorine Requirement for Growth in the Rat," *Bioinorganic Chemistry* 1:331-8, 1972.

Messer, H. H., Armstrong, W. D., and Singer, L.: "Fertility Impairment in Mice on a Low Fluoride Intake," *Science* 177:893-4, September 8, 1972.

ENGINEERING ASPECTS

A. Fluoride Compounds.

1. Chemicals Available

ORDER OF DESIRABILITY OF THREE FLUORIDE COMPOUNDS

	SODIUM FLUORIDE	SODIUM SILICOFLUORIDE	HYDROFLUOSILICIC ACID
Cost	2.5	1.0	3.0
Solubility, gal. solution required	17.0	65.0	1.0
Storage space required	1.5	1.0	2.5
Limitations, feeder space	2.0	2.0	1.0
Corrosiveness	1.0	1.5	2.0
Incrustation in feeder	3.0	2.0	1.0
Bulk handling problems	2.0	2.0	1.0
Hazards to operators	1.0	1.5	1.0

2. Storage and Handling

B. Fluoride Feed Equipment.

1. Solution Type

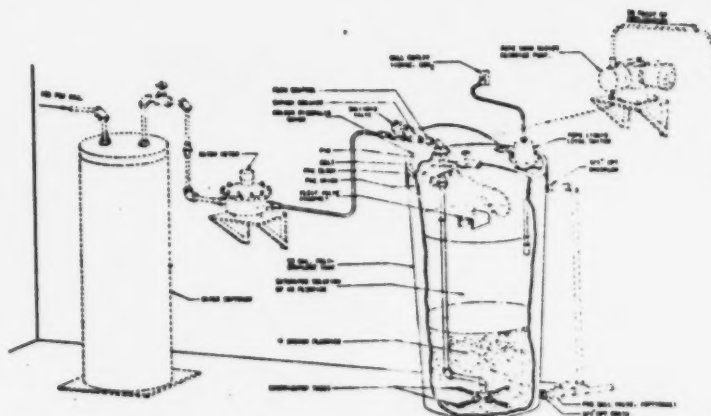
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2. Dry Type

a. Volumetric

b. Gravimetric (loss-in-weight)

3. Dissolvers



Specifications

Tank -- 50 gallons, graduated translucent polyethylene.
Cover -- Molded Fiberglass with built in recesses for liquid level switch and solenoid valve assembly.
Total Capacity -- 300 lbs. of granular or powder grade of sodium fluoride or bifluoride.
Refill Capacity -- 100 lb. ideal, 200 lb. maximum.
Input water flow rate -- Fixed at 4 GPM.
Input water pressure -- 20 psi minimum to 125 psi maximum.
Chemical pump intake -- Floating type.
Electrical -- 115 volts AC, 60 Hz, single phase.
Overall Height -- 45.5 inches maximum.
Overall Width -- 30 inches maximum.
Drawing 3475

TYPICAL FLOW RATE APPLICATIONS

PCP CHEMICAL PUMP	Maximum Flow to be fluoridated at 1 ppm	Minimum Flow to be fluoridated at 1 ppm
Model 12791-11	480 GPM	3.6 GPM
Model 9791-11	750 GPM	75 GPM
Model 5791-111	1500 GPM	150 GPM
Model 5791-121	3000 GPM	300 GPM
Model 3791-121	10800 GPM	1080 GPM

C. Feed Rates.

1. Characteristics of Fluoride Compounds

Item	Sodium silicofluoride (Na_2SiF_6)	Sodium fluoride (NaF)	Hydrofluosilicic acid (H_2SiF_6)
Form.....	Powder	Powder	Liquid
Molecular weight ...	188.05	42.00	144.08
Commercial purity, %	98.5	90-98	.22-30
Fluoride ion, % (100% pure material)....	60.7	.45.25	79.2
Weight (lb per cu ft).	55-72	65-90	10.5 lb/gal
Storage space, cu ft per 1,000 lb F ion.	23-30	22-34	54.73
Lb required per mg for 1.0 ppm F at indicated purity....	14.0	18.8(98%)	35.2(30%)
Solubility (g per 100 g H_2O) at 25°C (77°F).	0.762	4.05	Infinite
Gal. saturated solution required per mg water at 25°C and 1.0 ppm F	219	55.6(98%)	3.35
pH of saturated solution	3.5	7.6	1.2(1% sol)

2. Feed Rate Calculations

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a. Gravimetric Feed

When a treatment plant is feeding solid chemicals, such as NaF or Na_2SiF_6 , the operator is usually looking for a figure which would tell him how many pounds of chemical he should be adding per hour. The operator will know his rate of water production and hopefully what concentration, ie. ppm, of F^- he wants in the finished water. Table 1 will give the purity, expressed in F^- , of the chemical which the operator is using. With this data it is possible to calculate the rate of feed of his fluoride chemical.

In order to carry out the calculations one formula which can be used is the following:

$$\text{Rate}_1 \times \text{Concentration}_1 = \text{Rate}_2 \times \text{Concentration}_2$$

where Rate_1 = the rate of water production of the plant; this figure should be multiplied by an appropriate factor to convert the units to those units which fit, ie. multiply by 8.3 lbs/gal if the answer is to be expressed in lbs F^- , by 3.8 liters/gal when metric volume is wanted.

Concentration_1 = the concentration wanted in the final product. If a certain natural content exists it can be subtracted in this portion of the calculation.

Example: 1.2 ppm of F^- is wanted as a final conc. but 0.6 ppm F^- exists naturally. Therefore

$$\frac{1.2 \text{ lbs } \text{F}^-}{10^6 \text{ lbs } \text{H}_2\text{O}} - \frac{0.6 \text{ lbs } \text{F}^-}{10^6 \text{ lbs } \text{H}_2\text{O}} = \frac{0.6 \text{ lbs } \text{F}^-}{10^6 \text{ lbs } \text{H}_2\text{O}}$$

Rate_2 = This is the rate at which the fluoride chemical must be fed in order to produce the desired concentration of F^- .

Concentration_2 = This is really an expression for the purity of the fluoride chemical. This number can be obtained from Table 1. If the chemicals were 100% pure

this correction would not be necessary however since most of the fluoride chemicals contain only a fraction of fluoride it is necessary.

Some examples of the use of this formula are shown next.

Example 1:

How many lbs of F^- should be fed in a 1 MGD plant that uses Na_2SiF_6 and needs a 1.2 ppm conc. of F^- in the final product.

Example 2:

If a plant produces 200 gal per minute and wishes to feed 28% H_2SiF_6 until a 1.2 ppm fluoride content is carried in its final effluent, at what rate should this H_2SiF_6 be fed expressed in pounds per hour.

b. Solution Feeds:

In many small plants the fluoride is made up into solutions and fed as a liquid. Machinery for feeding such liquids will in all probability be calibrated in milliliters per minute.

Fluoride in a quantity of feed solution will be diluted upon its addition to water produced by the plant. The rate of feed is equal to the rate of H_2O production multiplied by the desired concentration of fluoride in the H_2O all of which is divided by the concentration of fluoride in the feed solution.

A saturator for example under proper conditions will feed a constant 4% of NaF to the treated water. This 4% solution is approximately 18,000 ppm F. Using this figure of 18,000 ppm F^- the rate of feed can easily be calculated using the same formula as we have been using.

Example 3:

A 20,000 gpm plant using a saturator wishes to have 1.2 ppm F^- into finished water at what rate in milliliters per/min should they feed.

C. Example Solutions:

Example #1

$$R_1 \times \text{Conc}_1 = R_2 \times \text{Conc}_2$$

$$\frac{1 \times 10^6 \text{ gal}}{\text{day}} \times \frac{8.3 \text{ lbs H}_2\text{O}}{\text{gal}} \times \frac{1 \text{ lbs F}^-}{10^6 \text{ lbs H}_2\text{O}} = x$$

$$\times \frac{60.7 \text{ lbs F}^-}{100 \text{ lbs Na}_2\text{SiF}_6}$$

$$\frac{\frac{8.3 \text{ lbs F}^-}{\text{day}}}{.607 \text{ lbs F}^-} = x = 13.67 \frac{\text{lbs Na}_2\text{SiF}_6}{\text{day}}$$

$$\frac{\text{lbs Na}_2\text{SiF}_6}{\text{day}}$$

Example #2

$$\frac{200 \text{ gal}}{\text{min}} \times \frac{8.3 \text{ lbs H}_2\text{O}}{\text{gal}} \times \frac{1.2 \text{ lbs F}^-}{10^6 \text{ lbs H}_2\text{O}} = x$$

$$\times \frac{.222 \text{ lbs F}^-}{\text{lbs of 28\% sol.}}$$

$$\frac{1992 \text{ lbs F}^-}{10^6 \text{ min}}$$

$$\frac{.222 \text{ lbs F}^-}{\text{lbs of 28\% sol}} = x = \frac{8973 \text{ lbs of 28\% sol}}{10^6 \text{ min}}$$

lbs of 28% sol

$$x = \frac{.009 \text{ lbs of 28\% sol}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}}$$

$$x = \frac{0.54 \text{ lbs of 28\% sol}}{\text{hr}}$$

Example #3

$$\text{Rate}_1 \times \text{Conc}_1 = \text{Rate}_2 \times \text{Conc}_2$$

$$20,000 \frac{\text{gal}}{\text{min}} \times 1.2 \text{ ppm} = x \times 18,000 \text{ ppm}$$

$$\frac{24,000 \text{ gal} \times \text{ppm}}{\text{min}}$$

$$\frac{\text{min}}{18,000 \text{ ppm}} = x = 1.33 \frac{\text{gal}}{\text{min.}}$$

$$x = 1.33 \frac{\text{gal}}{\text{min}} \times \frac{3.78 \times 1000 \text{ ml}}{\text{gal}}$$

$$x = 5054 \frac{\text{ml}}{\text{min}}$$

DISINFECTION

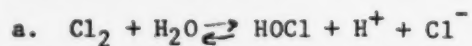
1. Purpose of Disinfection:

a. Destruction of Pathogens.

b. Types of Organisms.

- (1) Bacteria (typhoid, cholera)
- (2) Virus (hepatitis, polio)
- (3) Cyst (endamoeba histolytica)
- (4) Nematodes

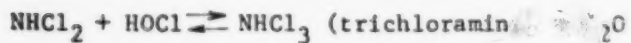
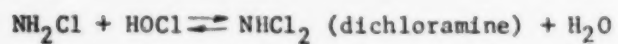
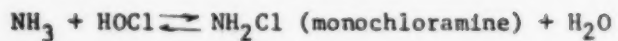
2. Chlorine Chemistry:



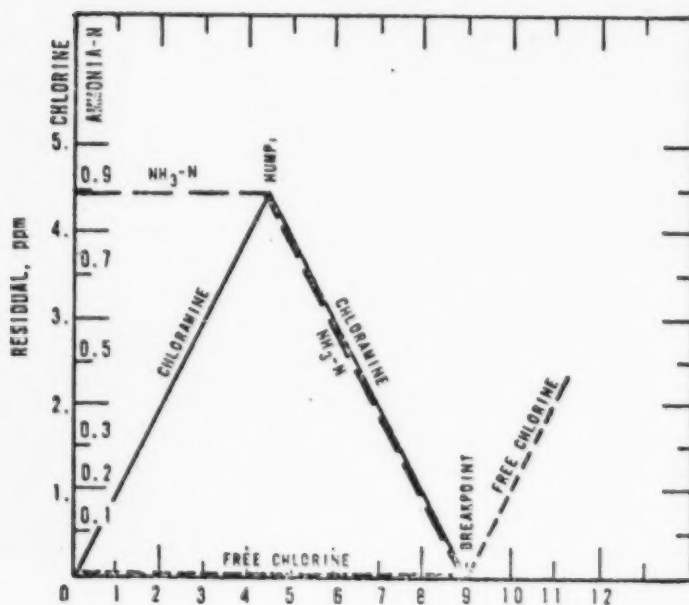
Percentage of Chlorine Species Present at Different
pH Levels

<u>pH</u>	<u>% HOCl</u>	<u>% OCl⁻</u>
5 and Below	100	0
6	97	3
7	73	27
7.4	50	50
9	3	97
11	0	100

c. Chlorine - Ammonia Reactions.



d. Breakpoint Chlorination.



Chlorine residual curve.

e. Effectiveness of Different Types of Chlorine.

- (1) Destruction varies with type of organism.
- (2) Destruction varies with chlorine form.

Concentrations of Forms of Active Chlorine to Yield 99 Percent
Germicidal Effect in 10 Minutes at 5°C

Type of Organism	Required Concentration ppm				
	HOCl	OCl ⁻	NH ₂ Cl	Free Cl at pH 7.5	Free Cl at pH 8
Enteric bacteria	0.02	2	5	0.04	0.1
Viruses	0.002-0.4	to 20	100	up to 0.8	up to 2
E. histolytica, cysts	10	1000	20	20	50
Bacterial spores	10	>1000	400	20	50

Morris, J. C. "Future of Chlorination", Journal of the American Water Works Association 58, 11, 1475-1482, November 1966.

f. Other Factors Which Affect Chlorine Residual.

- (1) pH
- (2) Chlorine - ammonia ratio
- (3) Organism
- (4) Temperature
- (5) Contact time

3. Control of Chlorination:

a. Point of Application.

b. Chlorine Demand.

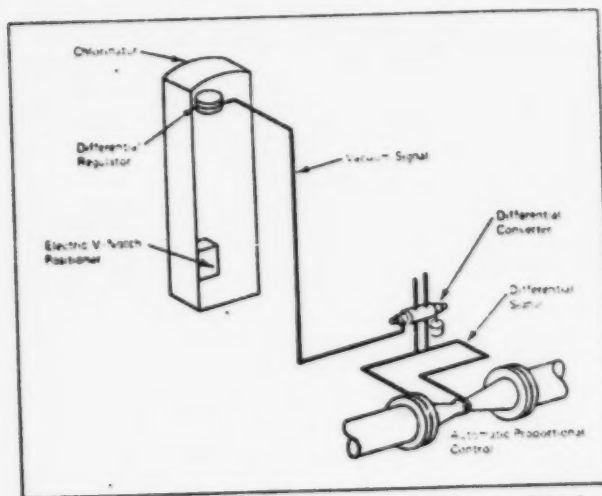
c. Chlorine Residual.

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- (1) Orthotolidine (OT)
- (2) Orthotolidine - Arsenite (OTA)
- (3) Amperometric Titration
- (4) N-diethyl - p-phenylene diamine (DPD)

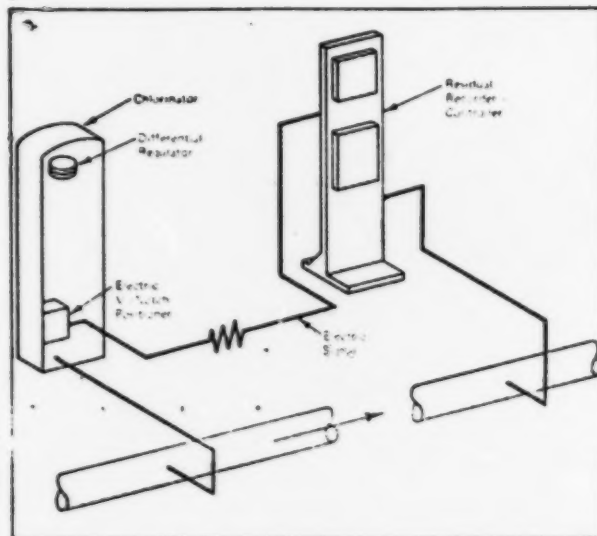
d. Automatic Residual Analyzers.

- (1) Open Loop Control



Open-Loop-Control Chlorination—Vacuum Signal

(2) Closed Loop Control

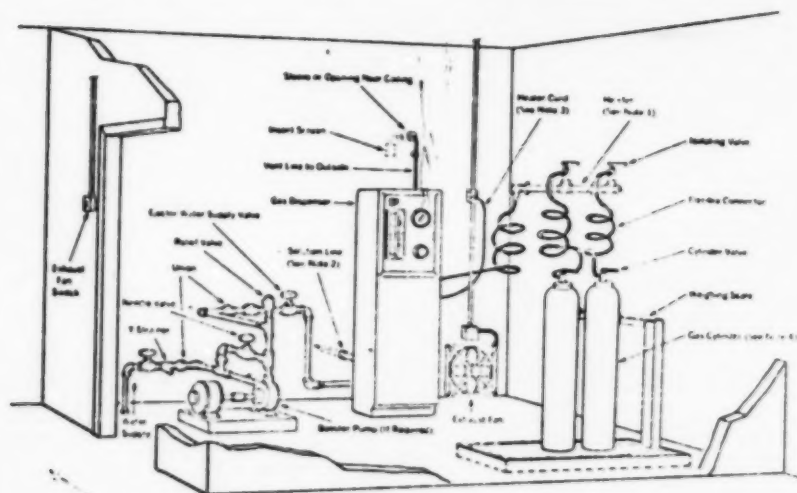


Direct-Residual or Closed-Loop-Control Chlorination

4. Chlorination Equipment:

- a. Weighing Scales
- b. Flexible Coils
- c. Manifold or Header
- d. Chlorinator
- e. Evaporator
- f. Ejector

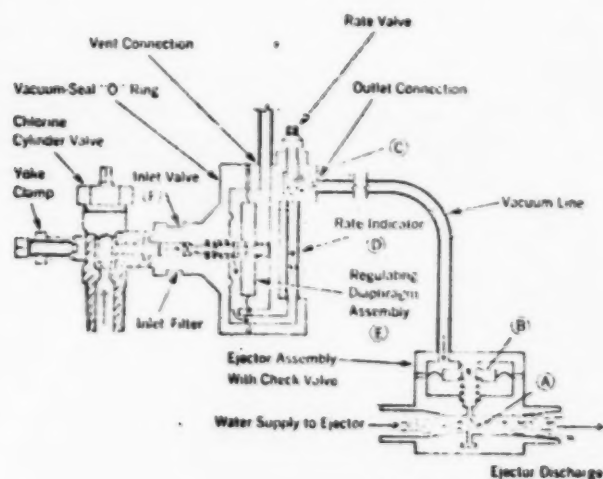
g. Typical Gas-Dispenser Installation



1. Issue 214 on Northside of 800 Carlton Street Place for
Glenview 10th Street to 800 Carlton Street, Glenview, Illinois
2. Sanitation Line Tree Removals (Trees on Mainstem Glenview
Road Right and Left) Water and Sewer Mainline Construction
3. 11/17/18 Sanitary Physics, 1000 N. Western St. copy required for
signature
4. Number of City Employees Used Depends on the City
Workload Rates of Employees

Typical Gas Dispenser Installation

h. Typical Cylinder Mounted Installation



Advance Gas Chlorinator Flow Diagram

1. Hypochlorite Feeders

(1) Dry-feed

(2) Solution feed

5. Other Methods of Disinfection:

a. Ozone

b. Surfactants

c. Bromine

d. U.V. Radiation

e. Heat

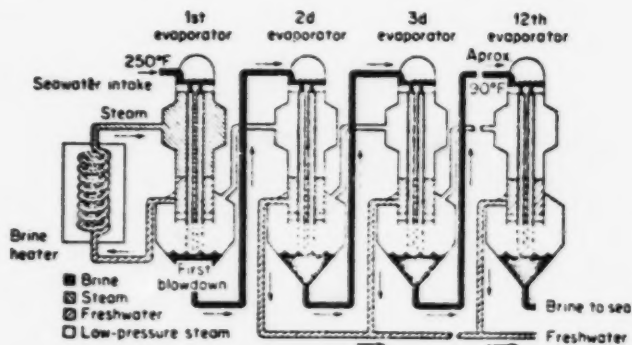
f. Ultrasonic and Pressure

g. Iodine

DESALINATION

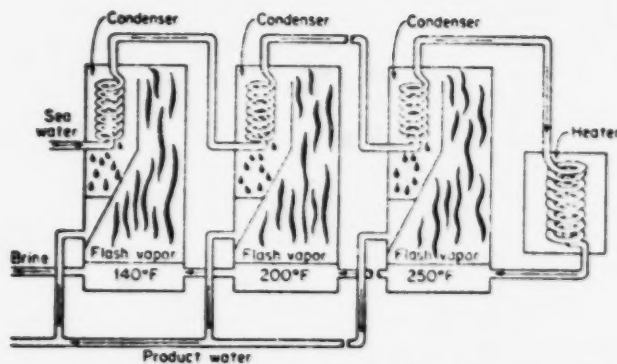
1. Distillation:

a. Long Tube Vertical Distillation Process.



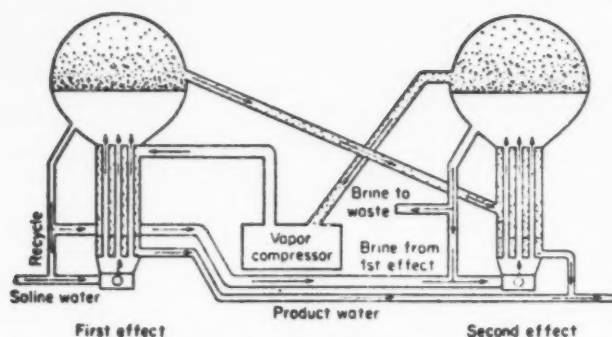
Simplified diagram of long-tube vertical distillation process (U.S. Department of the Interior, Office of Saline Water).

b. Multistage Flash.



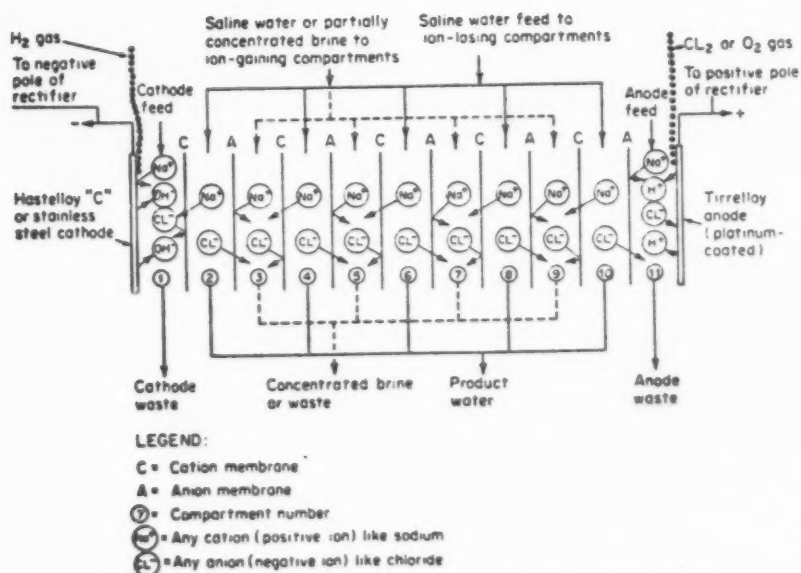
Simplified diagram of multistage flash distillation process (U.S. Department of the Interior, Office of Saline Water).

c. Vapor Compression.



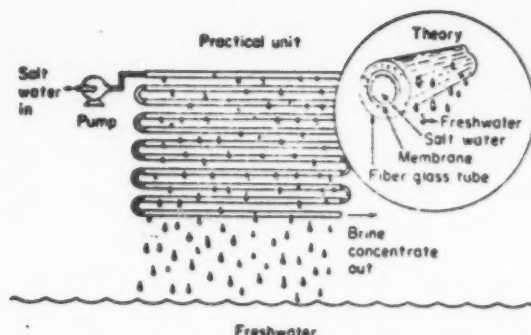
Simplified diagram of vapor-compression distillation process (U.S. Department of the Interior, Office of Saline Water).

2. Electrodialysis:

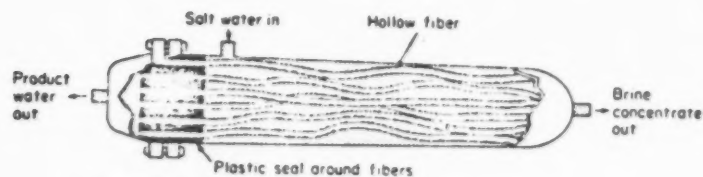


Basic ion and water flow in an electrodialysis stack (Ionics, Incorporated).

3. Reverse Osmosis:



Simplified illustration of tubular reverse osmosis (U.S. Department of the Interior, Office of Saline Water).



Simplified illustration of hollow-fiber reverse osmosis process (U.S. Department of the Interior, Office of Saline Water).

4. Ion Exchange:

5. Case Histories:

Saline Water Conversion Plants Owned by Water Utilities in the U.S.A. (as of July 1, 1969)

Location	Owner	Capacity, gpd	Process	Start-up date	Raw water TDS, ppm
Coalinga, Calif.	City of Coalinga	28,000	ED	1959	2,400
Buckeye, Ariz.	Town of Buckeye	850,000	ED	1962	2,200
Port Mansfield, Tex.	Port Mansfield PUD	250,000	ED	1965	2,400
Catalina Island, Calif.	Southern California Edison	150,000	MSF	1965	55,000
Key West, Fla.	Florida Keys Aqueduct Commission	2,600,000	MSF	1967	55,000
Dell City, Tex.	City of Dell City	70,000*	ED	1967	2,700
Siesta Key, Fla.	Siesta Key Utilities Authority	1,200,000†	ED	1969	1,300
		4,948,000			

* Expanded from 50,000 to 70,000 gpd in 1968.

† Expandable to 2 mgd.

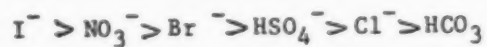
NITRATE REMOVAL

1. Health Aspects of Nitrates

2. Treatment for Nitrate Removal:

a. Ion Exchange.

(1) Ion Selectivity: Dowex 21K



(2) Regeneration

(3) Costs

CORROSION CONTROL

1. Corrosion:

- a. Definition
- b. Factors Which Affect Corrosion
- c. Electron Transfers
 - (1) Anodic Reactions
 - (2) Cathodic Reactions
- d. Corrosion Rate

2. General Classifications by Water Quality:

- a. No Minerals--Dissolved Oxygen Present
- b. No Minerals--Dissolved Oxygen Absent
- c. Noncarbonate Minerals--Dissolved Oxygen Present
- d. Carbonate Minerals (No Calcium)--Dissolved Oxygen Present
- e. Minerals--Dissolved Oxygen Absent
- f. Calcium Salts--Dissolved Oxygen Present

3. Types of Corrosion:

- a. Univorm Corrosion
- b. Pitting Corrosion
- c. Galvanic Corrosion
- d. Concentration-cell Corrosion
- e. Crevice Corrosion
- f. Dezincification
- g. Graphitization
- h. Stress Corrosion
- i. Corrosion Fatigue
- j. Erosion Corrosion
- k. Cavitation Corrosion
- l. Stray Currents

4. Corrosion Factors:

- a. Effect of Velocity
- b. Effect of Temperature
- c. Sulfate Reducing Bacteria

5. Corrosion Control:

a. Protective Measures Against Corrosion

b. Chemical Control

(1) Polyphosphate Treatment

(2) Silicate Treatment

6. Water Stabilization:

a. Saturation Index $SI = pH - pH_s = pH - [(pK_2' - pK_s') + pCa^{++} + pALK]$

Where: pH = Actual pH of the water
pH_s = pH at saturation
(pK₂' - pK_s') = Empirical Constants
pCa²⁺⁺ = The negative logarithm of the calcium
 ion concentration
pALK = The negative logarithm of the total
 alkalinity expressed in terms of
 equivalents per liter

b. pH Adjustment

DISPOSAL OF WATER PLANT WASTES

1. Introduction:
 - a. Origin
 - b. P & P on Sludge Disposal
2. General Characteristics of Wastes:
 - a. Suspended Solids
 - b. Oxygen Demanding Substances
 - c. Turbidity and Color
 - d. Toxicity
3. Special Characteristics of Wastes:
 - a. From Raw Water
 - b. From Chemicals Added
 - c. Filter Backwash
 - d. Exchange Brines
 - e. Screenings
4. Operations Affecting Receiving Waters:
 - a. Reservoir Cleaning
 - b. Filter Media Cleaning
5. Methods of Separation:
 - a. Polymer
 - b. Dewatering
 - (1) Drying Beds
 - (2) Vacuum Filters
 - (3) Centrifuges
 - (4) Lagoons

6. Disposal to Environment:

- a. Incineration - Air
- b. Ocean Disposal
- c. Land Disposal - Landfill

7. Recovery of Usuable Waste Products:

- a. CaO
- b. Calcium Phosphate (soft water)
- c. Aluminate

PROBLEM SET

Suggest reasonable solutions to the following practical problems in water production and distribution. Discuss briefly the cause of the problem and the rationale of your suggested solution; also discuss any alternative solutions:

1. a. Small red worms appear in the consumers supply.
b. A ground water, which is only chlorinated prior to distribution, is creating consumer complaints of "red water".
2. a. The treatment plant is occasionally bothered by algal growths.
b. The carrying capacity of the distribution system is slowly decreasing. The treatment process involves aeration and softening.
3. a. Taste and odor complaints for water from a ground water supply and for a surface supply.
b. Reduced filter runs for a softening plant.
4. A municipality is down to 8 days supply of chlorine (normal inventory is 20 days) and approach you for help. What would be the approach if the shortage is caused by (a) a strike at the repackaging plant; or (b) the repackager is out of chlorine? What possible alternatives could be suggested to assure that drinking water is properly disinfected?
5. Below are some raw water quality data for three sources. For each source, indicate the water quality parameters which should be adjusted by treatment.

<u>Constituent</u>	<u>A</u>	<u>B</u>	<u>C</u>
Total Hardness (mg/l as CaCO_3)	250	780	10
Iron (mg/l)	0.25	1.7	0.02
Turbidity (units)	260	0.07	27
Odor (T.O.N.)	1	1	50
Nitrates (mg/l as NO_3)	0.0	53	2.8
Temperature ($^{\circ}\text{F}$)	62	75	80
Total Dissolved Solids (mg/l)	370	1020	32
Sulfates (mg/l)	10	120	0.0
Fluorides	0.2	8.1	1.0

6. In conducting a group tour of a surface water treatment plant, a plant manager says the following:

"Based upon the flow in the plant, alum is added in the rapid mix unit to agglomerate the dissolved solids in the raw water and these are totally settled out in the sedimentation basin. The sedimentation basins are on your right and their function is to allow time for the floc particles to settle to the bottom and thence to be discharged back into the creek." At this point he mumbles something under his breath and says, "Some eco-freaks have complained about our sludge discharge but we are just returning to the stream the material that we removed from the original water; therefore, we don't consider it to be a problem. Any questions."

He doesn't know that the strange looking person lurking in the back of the group is a DER inspector. What comments do you have regarding his presentation?

When the manager gets to the sand filters he says:

"Here is where the solids are strained out of the water. The filters are made of regular sand, but when they built the filters they placed the finest sand grains on top. After filtration the water is sterilized with chlorine and of course we test all of the water for the presence of pathogenic agents." After a furtive glance over the group he says "let's see if the strange looking person in the back thinks he's an expert on filtration and disinfection too?"

Any comments?

7. The water supply source for Nowheresville is a surface impoundment and the City owns the entire watershed immediately around the reservoir. No treatment is provided the water except for disinfection and pH adjustment. After each significant rainfall your office is inundated with calls from the citizenry of Nowheresville concerning the turbid water and the fact that their pet had just died from drinking the stuff.

What type of information should you secure from the authority to determine if, in fact, there is a health problem related to the run-off? What types of recommendations would you make to the City concerning treatment, watershed management, land use on the watershed, and recreation on the watershed and the reservoir?

8. In response to one of your inspection questions the utility manager says, "We have no cross-connection control program in the system because we have no cross-connections." What is your response to this statement and what action do you propose to refute it?

After the above course of action the utility manager is convinced that he does have a cross-connection problem and asks you, "How do I go about setting up a control program?"